The subject of the present invention is a system for monitoring the movements, if any, of construction work parts.

5   More precisely, the present invention relates to a system or an installation which allows the monitoring of the movements, if any, of the various constituent elements of an engineering construction work under the effect of external causes such as land movements or
10   risks of subsidence due for example to tunnel boring under the said engineering construction work.

The invention applies in particular but not exclusively to the monitoring of buildings in an urban area during
15   the boring of a tunnel under these buildings. It is indeed understood that this boring may engender movements of the structure of these buildings and that it is vital to be informed thereof immediately so as to be able to remedy same.
20

Systems for monitoring the movements, if any, of engineering construction work parts are known which consist of an assembly made up on the one hand of a motorized theodolite and on the other hand of targets
25   associated with the theodolite, these targets being on the one hand positioned on parts that are not liable to be affected by movements, that is to say reference targets and, on the other hand, monitoring targets that are fixed at suitable locations on the construction
30   work parts to be monitored. The position of the reference targets may be known with high accuracy. The theodolite or similar apparatus makes it possible, by successively sighting the reference targets and the monitoring targets, to determine the coordinates in
35   space of the reference targets and of the monitoring targets. It is indeed understood that, because the theodolite must usually be placed in the area liable to be affected by movements, it is necessary to be able to accurately determine, on the basis of the reference

targets, the position of the theodolite and consequently the position of the monitoring targets.

As is well known, the theodolite is controlled so as to
5 successively and periodically sight the reference targets and the monitoring targets, measuring for each target its polar coordinates: distance, horizontal angle, vertical angle. Usually, the theodolite is equipped with a laser beam generator and the reference
10 and monitoring targets comprise a prism which returns the laser beam to the theodolite when the latter is correctly pointed at the target. It is thus possible to measure the polar coordinates of the reference targets and of the monitoring targets with respect to the
15 theodolite, the Cartesian coordinates of the monitoring targets being calculated by the monitoring centre.

By comparing the coordinates of the monitoring targets for successive instants of measurement of coordinates,
20 it is possible to detect movements, if any, even if the latter are of very small amplitude. Indeed, in order to have a reliable monitoring system, it is necessary to be able to detect displacements or movements of the order of a millimetre.
25
Although theodolites may have a relatively big range, it may happen, in certain situations, that the possibilities for setting up the theodolite do not make it possible, with the aid of a single theodolite, to
30 perform the monitoring of all the construction work or of all the buildings. This is especially true in an urban area.

Furthermore, it is not always possible, in the
35 environment of the monitoring area and in particular in the case of an urban environment, for there to be areas that are not liable to be affected by movements which allow the placement of reference targets in such a way

that these targets allow the determination in three
dimensions of the position of the theodolite.

There therefore exists a genuine need for a system for
5   monitoring the movements, if any, of construction work
parts which makes it possible to efficiently monitor
the various parts of an engineering construction work
of considerable dimensions and under conditions in
which it is difficult to set up monitoring or reference
10 targets and in particular in an urban setting.

An object of the present invention is to provide a
system for monitoring the movements, if any, of
engineering construction work parts which allow the
15 monitoring of an engineering construction work of
considerable dimensions even if the conditions, for
example in an urban setting, are unfavourable to the
placement of the theodolites and of the reference or
monitoring targets.
20
To achieve this aim, according to the invention, the
system for monitoring the movements, if any, of
construction work parts is characterized in that it
comprises:
25 -   a plurality of measurement taking stations able to
sight targets and capable of being mounted at least in
part on the said construction work parts;
-     a plurality of reference targets linked to at
least one station;
30 -   a plurality of monitoring targets mounted on the
said construction work parts, at least some of the said
monitoring targets being associated with at least two
stations;
-     means of control of each station for measuring at
35 successive instants the coordinates, preferably the
polar coordinates, of the reference targets and of the
monitoring targets which are associated therewith with
respect to the said station; and

-    means of processing the coordinates of the reference targets and of the monitoring targets computed by the said stations at the said successive instants so as to deduce therefrom a displacement, if any, of a monitoring target between two measurement instants.

It is understood that the monitoring system according to the invention comprises a plurality of measurement taking stations, for example of motorized theodolites, which may therefore be deployed suitably to allow the monitoring of all of the engineering construction work. However, because, with the various measurement taking stations there is always associated at least one monitoring target corresponding to at least two measurement taking stations, it is possible to couple, during the mathematical processing of the measured coordinates of the monitoring targets and of the reference targets, the information relating to the position of the whole set of these targets. It is thus possible to circumvent situations in which it would not be possible to set in place a sufficient number of reference targets associated with each measurement taking station. Stated otherwise, the measurement taking stations are intercoupled by way of the monitoring stations common to two or more of two measurement taking stations.

From a practical point of view, in order for it to be possible for a monitoring target to be "seen" by two measurement taking stations, it may be necessary for this target to be double. For example, the target will comprise two prisms whose relative positions are strictly fixed.

In the present text, the expression "monitoring target" should therefore be understood to mean either a simple target or a double target.

Furthermore, it should be pointed out that the reference targets are not necessarily strictly fixed. It is sufficient that their precise position can be determined and reset from time to time.

According to a preferred mode of implementation, the monitoring system furthermore comprises:
- a monitoring centre comprising the said processing means; and
- means for transmitting from each station to the said monitoring centre the said polar coordinates of the monitoring and reference targets measured by the said stations at the said successive instants.

It is understood that, in this preferred embodiment, the monitoring system furthermore comprises a monitoring centre which is connected by any suitable means, for example by radio transmission, to the various measurement taking stations in such a way that this monitoring centre receives, at predetermined successive instants, the relative coordinates of the reference targets and of the monitoring targets measured by the various measurement taking stations. This monitoring centre comprises the means of mathematical processing of the various information items received, this making it possible in tandem with the receipt of the set of measurements performed by the various measurement taking stations at each instant to correlate, for example by the method of least squares, the measurements performed so as to optimize the determination of the absolute coordinates of the monitoring targets on account of the redundancy of the information. The calculation of the absolute effective coordinates of the various monitoring targets makes it possible to detect in real time a movement, if any, of a part of the engineering construction work associated with one of the monitoring targets.

Other characteristics and advantages of the invention will become better apparent on reading the description which follows of several embodiments of the invention, given by way of nonlimiting examples. The description makes reference to the appended figures, in which:

- Figure 1 is a simplified view of an exemplary embodiment of a measurement taking station;

- Figure 2 is a diagram showing the setup of reference targets and of monitoring targets around a measurement taking station;

- Figure 3 illustrates the whole of the monitoring system in a first configuration;

- Figure 4 is a diagrammatic view of the double target used for the monitoring targets common to two measurement taking stations; and

- Figure 5 shows a second exemplary implementation.

Referring firstly to Figure 1, an exemplary embodiment of a measurement taking station built around a motorized theodolite will be described. However, it goes without saying that the invention could be implemented with other measurement taking stations so long as the latter make it possible to determine the relative polar coordinates of the various reference or monitoring targets corresponding to the measurement taking station.

The station 10 comprises a base or chassis 12 that can be fixed at a suitable location on the construction work in order to perform the monitoring. Mounted on this chassis 12 is a theodolite 14 rotatable about the vertical axis XX'. The rotation of the theodolite 14 with respect to the chassis 12 can be controlled by a motor 16 associated with a control circuit 18. The theodolite 14 comprises in particular an optic for emitting a laser beam 18 mobile about a horizontal axis cutting the vertical axis XX'. The laser beam emitted by the optic 18 makes it possible to sight the targets by suitably controlling the motor 18 and an actuator 20

for rotating the optic about the horizontal axis. This system can be servocontrolled and programmed to successively sight various targets at predetermined instants. In the station there are also processing and

5 memory circuits such as 22 which make it possible to temporarily store, for each sighting of a target, the identification of the reference or monitoring target as well as the polar coordinates of this target with respect to the theodolite. The measurement taking

10 station 10 also comprises a radio emitter 24, or analogue means of transmission, capable of emitting, whenever a measurement of the coordinates of the targets associated with the station is taken, the identification of each target as well as its relative

15 polar coordinates.

Represented in Figure 2 is an exemplary setup of monitoring targets C_i and of reference targets C'_i around a station 10. The monitoring targets C_i are

20 fixed on the various parts of the construction work which is liable to undergo movements. On the other hand, the reference targets C'_i are arranged and fixed on parts of the environment of the construction work that are not a priori liable to be affected by

25 movements. Furthermore, through any suitable means, the absolute position of the reference targets C'_i is known with high accuracy. The position of the reference targets is not necessarily strictly fixed, although the targets are mounted in links outside the area affected

30 by the movements. It suffices that the exact position of these targets can be reset periodically. It is necessary for the reference targets C'_i to be arranged in such a way that they allow absolute charting in three dimensions of the measurement taking station 10.

35 The monitoring targets C_i may of course be arranged in the effective field of action of the theodolite and in particular therefore in direct line of sight of the station.

It is understood that the conditions imposed in respect of the reference targets and the monitoring targets imply that it is impossible to monitor a big construction work with the aid of a single measurement taking station.

Referring now to Figure 3, the whole of the monitoring system in accordance with the invention will be described in a first configuration. The area H of the engineering construction work whose movements, if any, have to be monitored and detected has been represented by dashes. One is concerned for example with a street under which a tunnel is being drilled, in an urban environment.

Represented in a simplified manner in this figure are several measurement taking stations S_1, S_2, S_3, S_4. These measurement taking stations are fixed at sites which are liable to be affected by movements so as to be able effectively to sight monitoring targets. Likewise represented in Figure 3 are areas R_1, R'_1 associated with the station S_1 and in which reference targets C'_i are arranged. In the same manner, reference targets associated with the station S_2 are arranged in the areas R_2 and R'_2, reference targets associated with the station S_3 are arranged in the areas R_3 and R'_3 and with the station S_4 are associated reference targets arranged in the areas R_4 and R'_4.

With each measurement taking station S_i are also associated monitoring targets C_i which are fixed on parts of the construction work to be monitored that are liable to be affected by movements, these targets C_i being of course arranged in the sighting field of the theodolites of the stations considered. Particular monitoring targets K_i are envisaged, that are arranged in areas T_1, T_2, T_3 that are situated in the sighting field of two adjacent measurement taking stations. Each area T_1, T_2, T_3 comprises several double targets K_i. It

is understood that each target of the type K_i forms the subject of the taking of relative coordinates by two adjacent stations, this making it possible to effect a coupling between the taking of coordinates of the whole
5 set of reference and monitoring targets associated with two measurement taking stations, and hence with the whole set of measurement taking stations.

Since it is desirable for the targets to be arranged
10 substantially perpendicularly to the laser beam of the station associated with them, the targets of the type K_i have a particular structure represented in Figure 4. These targets are in fact double. They comprise a rigid stand 26 on which are mounted two targets of standard
15 type 27 and 28. The monitoring targets 27 and 28 may be suitably oriented with respect to the two theodolites of the stations which will measure their coordinates. However, the relative coordinates of the targets 27 and 28 are fixed and in particular the distance which
20 separates these two targets is fixed. This particular feature will of course be incorporated into the calculation of the absolute coordinates of the monitoring targets.

25 The expression monitoring target should therefore be understood to mean simple, double or even possibly triple targets.

The monitoring system comprises, in addition to the
30 measurement taking stations and the reference or monitoring targets, be they simple or double, a monitoring centre 30. This monitoring centre 30 is equipped for example with radio receiver means 32 for receiving the relative coordinates measured by the
35 various stations and transmitted by the radio emitter 24 associated with them. This transmission of information from all the stations S_i to the centre 30 is carried out at each measurement taking period by the stations. The centre 30 comprises in particular logic

and digital processing means 34, for example a microprocessor, connected to the radio receiver 32 by storage and shaping circuits 36, permanent program memories 38, random access calculation memories and

5   nonvolatile data memories 40. The monitoring centre also comprises display means 42 making it possible, for example, to display for each measurement instant the calculated absolute coordinates of the various monitoring targets with indication of the target

10   considered. As will be explained later, the display means make it possible to display an alarm signal in the case where a movement of one of the monitoring targets is detected which exceeds a predetermined threshold. The display means 42 are connected to the

15   logic processing unit 34 by a control circuit 44.

The whole system operates as follows:
at each measurement instant, the theodolites of the measurement taking stations are ordered to log the

20   relative polar coordinates of the reference targets, of the simple monitoring targets and of the double monitoring targets which are associated with them. This coordinate information is transmitted at each measurement period to the monitoring centre 30. These

25   various relative coordinates taken by the theodolites are processed by the logic processing unit 34 which implements a mathematical processing algorithm stored in the permanent memory 38. As will be explained in greater detail later, the algorithm is of the least

30   squares type. For each series of measurements of relative coordinates, one obtains, by processing with the aid of the program, the absolute coordinates of the various monitoring targets be they simple or double, these absolute coordinates resulting in particular from

35   the correlation between the measurements made by the stations by virtue of the double targets K_i. These absolute coordinates of the monitoring targets are stored in the memory 40 and can be displayed on the display device 42. During the next measurement cycle,

the same process occurs, this making it possible to obtain the absolute coordinates of the various monitoring targets. Comparison with a reference state of these absolute coordinates of the various monitoring
5   targets obtained at each measurement cycle makes it possible to detect in real time a movement, if any, of one of the monitoring targets and therefore to trigger an alert. The periodicity of the measurements is determined as a function of the feedback sought in the
10   monitoring.

It is also important to stress that the invention allows global processing of the various measurement taking stations and hence of the whole of the
15   installation.

The setup, illustrated in Figure 3, of the targets, both reference and monitoring, corresponds to a favourable configuration on account of the fact that it
20   is possible to associate, with each measurement taking station, fixed reference targets. The set up represented in Figure 3 corresponds for example to the monitoring of the buildings along a main street, the reference targets being mounted on buildings in
25   perpendicular roads outside of the area liable to be affected by the movements.

As already indicated, the mathematical processing of the relative polar coordinates of "mobile" monitoring
30   and of the fixed reference targets from the likewise "mobile" measurement taking stations, which are redundant, is carried out by the method of least squares.

35   This method, which is well known in itself and is used in numerous fields, makes it possible to manage information, in redundant number, acquired with risks of error. On account of the redundancy of the

information, it makes it possible to detect the errors
and to improve the accuracy of the results obtained.

The calculation is iterative: a first calculation makes
it possible to establish a tailored set of solutions on
the basis of an approximate set of solutions
established on the basis of external elements. The
tailored set of solutions is then used as approximate
set of values and so on and so forth until the
convergence factor converges according to an accuracy
fixed in advance. The set of solutions that are adopted
is that which minimizes the sum of the squares of the
residuals corresponding to each coordinate.

During this mathematical processing, it is possible to
detect automatically whether certain targets regularly
exhibit a bigger residual than the other targets. These
discrepancies are generally attributable to artefacts
affecting the logging of the position of these targets,
these artefacts possibly being spurious reflections of
the laser beams, disturbances of the optical path of
the laser beams, etc.

It is thus possible to automatically identify the
targets corresponding to bigger residuals via a
mathematical processing of these residuals. These
targets are then deactivated and the mathematical
processing is resumed, ignoring the measurements
involving these targets. Thus, it is understood that
the configuration of the network of stations can be
managed dynamically.

The reference targets have accurately known absolute
coordinates whereas the monitoring targets and the
measurement taking stations are "mobile". The position
of the stations is recalculated each time from the
reference targets.

The great advantage of the use of the method of least squares within the framework of the present invention is the ability to process calculations blockwise. It allows the calculation of theodolites that can see no
5   or few reference targets, tying them to other theodolites via double monitoring targets K_i.

In certain cases, one may not benefit from this favourable situation. This will be the case, for
10   example, when it is not possible to associate a sufficient number of fixed reference targets with each measurement taking station. This is the case illustrated by Figure 5. Represented in this figure is a first measurement taking station S_1 with which are
15   associated a plurality of fixed reference targets C'_i and monitoring targets C_i arranged in the area U of sighting of the theodolite of station S_1. On the other hand, for the measurement taking stations S_2 and S_3, there is no possibility of setting up reference
20   targets. Monitoring targets C_i are of course associated with each of the stations S_2 and S_3. Furthermore, in the areas common to two adjacent measurement taking stations T_1 and T_2 are fixed double targets K_i. In particular, in the area T_1 are mounted double
25   monitoring targets in the fields of action of station S_1 and of station S_2 whereas double targets are mounted in the area T_2 common to the two stations S_2 and S_3. The remainder of the monitoring system is identical to that which is represented in Figure 3, in particular as
30   regards the monitoring centre.

It is understood that in this configuration and despite the absence of reference targets in respect of stations S_2 and S_3, it will be possible to perform this
35   monitoring and hence the determination of the absolute coordinates of the monitoring targets C_i in the areas corresponding to stations S_2 and S_3 by virtue of the correlation between the measurements resulting from the placing of the double targets K_i in the areas common to

two measurement stations T_1 and T_2. There must of course be a sufficient number of double targets K_i.

It should be stressed that, by virtue of the presence
5 of at least one double monitoring target, visible from two measurement taking stations, the system can operate in the case where a measurement taking station is not connected to a sufficient number of reference targets or it is connected to poorly distributed reference
10 targets.

Furthermore, as indicated previously by a target-associated mathematical processing of the residuals, during the implementation of the method of least
15 squares, it is possible to identify the targets the logging of whose position is affected by artefacts and to ignore the measurements involving the targets thus identified in calculating the polar coordinates of the other targets. It is thus possible to carry out dynamic
20 management of the monitoring system.